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Tests of Belt Connections

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TESTS OF BELT CONNECTIONS

BY

Emmett Emerson Fast

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
COLLEGE OF ENGINEERING
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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

EMMETT EMERSON FAST

ENTITLED TESTS OF BELT CONNECTIONS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

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TESTS OF BELT CONNECTIONS

I INTRODUCTION

Belt driving is probably the oldest method of transmitting power in existance at the present time. Its origin, or first application is entirely unknown, but we learn from the earliest mechanical records that it was used by the ancients, although in a very crude form. No doubt the fastening together , or the lacing of the ends of belts, was a difficult problem for them. Even at the present time, although there are many kinds of belt connections in use, it has never been fully decided which is the most satisfactory for the various kinds of work.

It is the purpose of this thesis to determine the relative value of the various types of connections on the market, by tests which will duplicate as nearly as possible, actual conditions.

While tension tests have been made of both the belting and connections, when new, it is probable that the connections deteriorate more or less rapidly with use. In order to obtain data on this point, three connections were tested in tension after being run for some time over small pulleys at high speed and the results compared with the tension tests on new connections. This durability test, as it may be called, proved of considerable value in determining the actual value of the connections tested and is believed to be entirely novel as applied

to belt connections.

The investigation here recorded was carried on under the direction of the Department of Theoretical and Applied Mechanics.

II THEORY AND AVAILABLE DATA

The theory of belt connections is analogous to riveted joints. The conditions which should exist in connections are that failure is as likely to occur in any one of the following ways as it is to occur in either of the other two; (1) the failure or the connection itself; (2) the failure of the "belt in tension" at the least cross-sectional area, which is on a line through the holes used for the connection; (3) the failure of the belt by tearing from the holes to the end of the belt or, as it will be called, "tearing out of the connection". The strength of any connection might be computed the same as for riveted joints, provided sufficient data were obtained. As with riveted joints, the efficiency of a belt connection is the ratio of the ultimate strength of the specimen connection to the ultimate strength of the belt. For example, the efficiency of the Hercules wire connection in table I is, -

$$\frac{445 \text{ Lb}}{770 \text{ Lb}} = 57.6\ \% \ .$$

Comparatively little data are available upon this subject. Such men, however, as Unwin, Towne and Flint have made a few tension tests upon new belt connections.

Unwin's results are shown in the following table,

	Pounds per inch width
Double belt, copper sewn ----------	1110
Single " ordinary laced joint ---------	473
" " butt laced ----------	265
" " joint scarfed and glued ------	544
" " grip fasteners ----------	242
" " Crowley's -- ----------	635
" " riveted in two rows ----------	394

Towne's tests are given in his investigation of "Adhesion of Leather Belts to Cast-Iron Pulleys". The averages of the trials were as follows;-

	Pounds per inch width
Three-inch belts broke through lace holes --	210
" " " through rivet holes--	382
" " " solid parts --	675

Giving an efficiency in the former(laced) of 31 % and in the latter (riveted) 56 %.

Prof. Flint of Maine State College also made a series of tests, and his conclusions were that metal fastenings cause the joints to fail at from 25 % to 50 % of the strength of the solid belt and the laced joints to rupture under a stress of from 30 % to 80 % of the strength of the solid belt.

The above data were obtained from Unwin's Elements of Machine Design; Cooper's Belts and Pulleys and from an account of Prof. Flint's tests in the "American Machinist" for Nov. 14, 1895.

III MATERIALS, TEST PIECES AND METHODS OF TESTING

The belting used in preparing the test specimens was four inch single (7/32 inches thick) and four inch double (3/8 inches thick). This was of the best oak bark tanned oxhide manufactured by the Chas.A.Shieren Co., Chicago, Ills.

The connections tested consisted of eleven different kinds in all; four styles of rawhide lacing; three of the metallic hinge type; one wire lacing; two of the belt hook type and one of belt studs. These included all the different types manufactured, although, probably not every individual kind on the market.

The rawhide lacing was the "Royal Worcester" (3/8 inch wide) manufactured by the Graton and Knight Manufacturing Co. of Chicago.

The hinge type consisted of the following makes; first, the "Jackson", which requires a special machine to attach it to the belt, and is manufactured by the Birdsboro Steel Foundry and Machine Co., Birdsboro,Pa. second and third, the "Flexible" steel hinge and the "Semiflexible" steel hinge, manufactured by the Flexible Steel Lacing Co., of Chicago.

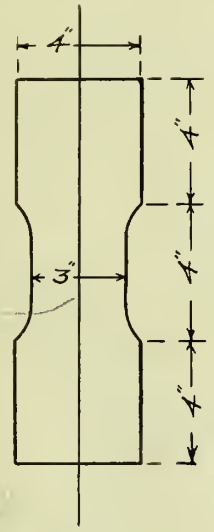
The wire used for the wire lacing is manufactured by the Hercules Composition Belt Lacing Co., of Chicago.

Of the two connections of the belt hook type, one is manufactured by the Bristol Co., of Waterbury Conn., the other by the Jewel Belt Hook Co. of Hartford Conn.

The belt studs listed as No.1 are manufactured by the Belt Hook Co. of Chicago. All the connections named above are

shown by detailed drawings in figure 4 - 8 inclusive. All the connections were donated for these tests by the makers.

In order to calculate the efficiency of the connections, it was necessary to obtain the ultimate tensile strength of the single belt. The test specimens for these were cut in lengths of twelve inches; three or single belt and three or double belt. They were trimmed to the shape shown in the figure below to insure breaking outside of the clamps.



These test specimens were gripped at each end by special clamps, which were designed for this work and are shown in the accompanying drawing (figure 1). The specimen with the clamps were then placed in the three-screw Olsen testing machine in the Laboratory of Applied Mechanics. Care was taken to insure an even pull on the two edges of the belt. This was the general method of making all the tension tests.

The specimens of belting for tension tests of connections were cut into lengths of fifteen inches. The connections were then made, using two lengths for each and tested in the Olsen testing machine as explained above. The tested connections were then cut out and replaced by new connections of a different kind. The purpose of this was to test the connections using different belt specimens so as to equalize as much as possible any variation in the strength of the belting.

Three specimens of each connection were tested in tension for single belting and for double belting.

All the connections were made by the writer with the exception of the Jackson machine lace, in which case the test specimens were sent to Birdsboro,Pa. and the connections made by the manufacturers. The belting for the durability tests were cut into twelve inch lengths and the pieces made up into one belt, no two connections of the same kind coming in succession. This belt was placed in the durability testing apparatus and run for an hour or two at a time; the total time aggregating twelve hours. After running this length of time, the connections withstanding the test, were placed in the Olsen testing machine and tested in tension. Any decrease in the strength as compared with the new connections indicated the amount of deterioration in the connections due to the durability test.

The durability testing apparatus consisted, mainly, of a counter shaft belted to a two-phase induction motor. The general arrangement of this apparatus is shown in figure 3. The test belt, as will be seen by the figure ran over a four inch pulley on the counter shaft and a four inch loose pulley on the lever mechanism below. A constant tension was maintained in the belt by placing weights in the box on the end of the lever, which was fastened to the wall at B. For the single belt a weight of seventy-five pounds was placed in the box; then the tension,T, in the belt due to the weight,W,which was acting at the end of the lever arm,AB, is found as follows;

Taking moments about B,

$$2T = 8W$$

Then $T = \frac{8 \times 75}{2} = 300$ pounds

The total tension considering the weight acting at C, then is,

$$T = 300 + 60$$

or $T = \frac{360}{8} = 45$ pounds tension per inch of width.

In a like manner the tension in the double belt was maintained at fifty pounds per inch of width. F.W.Taylor states that the ordinary rule is to keep a driving tension on a double belt of 65 pounds per inch of width, while Unwin recommends 112 pounds for double and 65 pounds for single belting. It was not possible in these tests, however, to carry so great a tension as the motor was not powerful enough to drive the apparatus when this was attempted. On this account a tension was maintained which would not overload the motor and yet be some where near the tension used in ordinary machine shop practice.

IV EXPERIMENTAL DATA AND DISCUSSION

The observed and completed data of the tests made with the different connections, are given in full in the tables I to IV inclusive. In tables I and III the fifth column gives the average ultimate tensile strength per inch of width; the sixth column the erficiency of the connections, and the seventh columns the approximate time required to connect the specimens of belting with each connection.

In tables II and IV the fourth column gives the ultimate strength per inch width, the fifth column the number or bends.

the sixth the percentage efficiency of the connections, the seventh the percentage deterioration and the eighth the approximate time required to connect the belt specimens with each connection. A bend in this case was made by the belt passing over a four inch pulley making an angle of contact of 180 degrees. The number of bends was obtained as follows;

$$V = \frac{\pi d}{12} \times R.P.M. = \frac{\pi \times 4}{12} \times 1800 = 1865$$

Where V = the velocity of belt in feet per minute. Length of belt tested = 23 feet.

Then $\frac{1865}{23} \times 2 = 162$ bends per minute since it passes over two pulleys. The number of bends was proportional to the length of time run and the latter was noted for each case. The total number or bends for the twelve hours test is then, 162 x 60 x 12 = 116,640.

The relative efficiencies of the different connections as determined from the tests are shown graphically on plates I and II. The ultimate tensile strength of the two belts, after the durability test, ~~were~~ was also ascertained by tension tests. It was found that the belting had deteriorated very little, if any, during the durability tests.

RAWHIDE LACE: It was found that for tension tests in single belt, designs No's. 1,2 and 4 (figure 10) caused tension failures in the belt, thus showing an excess of strength in the connection. If the number of strands were decreased the efficiency of the connection might be increased, because in using so many strands the holes of the belt are enlarged

thus reducing the cross-sectional area. No.3 bears out this statement; it had the fewest strands of any and failed in the connection by breaking two or three strands of the rawhide. In the double belt the tension tests showed failure of the strands in No's. 1,2 and 3 (see figure 13). No. 4 failed by tension in the belt, leaving the lacing intact, thus showing an excessive strength in the lacing. The efficiency in the former could therefore be increased by increasing the number of strands and in the latter by decreasing them.

The durability test, which shows the real value of the connections reveals the fact that in both the single and double belting No's. 1 and 4 are rather durable connections (see figure 11). When tested they failed by tension in the belt the same as in the new connections. No.3 lace also withstood the twelve hour run, while No.2 failed by the strands breaking in about half that time. In the double belt No's 2 and 3 failed by the strands breaking after only a few hours. It was found that by lacing these connections more loosely, yet uniformly, the life of the connection was greatly increased. The rawhide lacing is probably used more extensively than any other, yet where time is an important factor, it is not desireable; for, as these tests showed, on an average two or three times as much time was required to join the belt ends with it, as was required by any other connection. When, however, a belt is shifted by hand, as for example the cone pulley belt on an engine lathe, there is probably no other connection which will not cut or tear the hand. This ih one reason why this connection is so popular in the shops.

HINGE TYPE: The connections of the hinge type failed by tension in the belt in both single and double belting, under the tension test, with the exception of the "Semiflexible" in which case the hooks gradually straightened, thus pulling out of the belt (see figures 9 and 12). These connections were worn considerable by coming in contact with the pulley in the durability test and, when tested in tension, the connections gave away, leaving the belt intact in every instant with the exception of the Jackson in the double belt (see figures 11 and 14) and in the latter, the failure was by tension in the belt. It is evident that any reduction in the thickness of the metal in the "Flexible" or "Semiflexible" connection would reduce the force required to straighten the hooks, allowing them to pull out of the belt. Comparatively little time is required to insert one of these connections in the belt and the operation can be performed by even an unskilled workman.

HERCULES WIRE LACE: The wire lace which is used quite commonly in machine shops, proved to be one of the strongest connections in both single and double belting. It failed by tension (see figures 9 and 12) in the belt, thus showing an excessive strength in the lace, which can be decreased by using fewer strands and thereby increase its efficiency.

The standard belt punch used (3/32 inches in diameter) proved too large for two strands of wire and could be reduced to 1/16 inch to advantage. This connection proved to be rather disapointing in the durability test. It wore very rapidly by coming in contact with the pulley, although the strands were countersunk flush with the belt surface. It only ran an average

length of time of two and one-half hours in the single belt and one-half hour in the double belt; the failure occuring suddenly, breaking the wire in ten or fifteen places.

HOOK TYPE: The hook type of connection in the tension test failed the same in both single and double belting, the "Jewell"by "the tearing out of the connection" and the "Bristol" by the hooks of the connection straightening.

It was very noticeable in the durability test that these connections, being made of one piece of metal, make the belt very stiff at this point. This causes an excessive wear in the belt on each side of the connection due to the bending being concentrated there, especially when running over small pulleys. Failure in nearly all cases occured at this point (see figures 11 and 14) by tension in the belt. One advantage of those connections is the simple design which permits the connection to be made in the shortest time possible.

The Blake belt studs, tested in the single belt only, were found to fail by the heads of the studs cutting through the belt. Evidently the design could be improved by increasing the bearing area of the heads upon the belt. These connections showed very little wear from the durability test. They are well adapted for running over small pulleys, as the connection is almost as flexible as the hinge type. When properly constructed the studs do not come in contact with the pulley as do all other metal connections and therefore it has the least amount of slippage and is not worn by the pulley.

An attempt to select from these connections one which, for general use, would prove the best would probably place the

"Jackson" first. It is true that all the tests did not place it first in efficiency but a greater number of tests would probably confirm the choice. In all the tests made the effiency is consistantly high, especially so after the durability test which is of much greater importance than the tension test. A consideration of the lacing impresses one with its thoroughly rational design. First,wire is used which leaves the greatest cross-section of belt possible and instead of punching holes in the belt for the lacing, the wire is sharpened and acts as its own punch. The strands, only one to each hole, can therefore be spaced very closely together so that the stress is uniformly distributed accross the belt. Instead of soft wire as used for wire laces, the Jackson uses a stiff steel wire which has a high tensile strength. A hinge connection is made by the use of a rawhide pin which makes it very flexible and permits the belt to be removed from the machine,when desired, by removing the pin. A very ingenious scheme has been devised for use with this lace, by which a piece of belting is cut about a foot short and a piece of the same length used to fill the gap. When the belt stretches a shorter piece is substituted which proves economical of belting as the short pieces are used again and again. The stiff wire used in this lacing requires a machine for making the connection. This is in line with all modern progress which tends to substute machine for hand labor and thereby do better work in much less time.

V CONCLUSION

RAWHIDE LACING: (1) The design used should be as simple as possible and yet have the number of strands equal in strength to the cross-sectional area of the belt between the holes. (2) The connection should be laced uniformly yet not too taut, especially when used in double belting.

HINGE TYPE: (1) The hinge type is well adapted for small pulleys. (2) It has too much metal surface coming in contact with the pulley, thus causing an excessive amount of slippage and wear. Especially is this true of the "Flexible" and of the "Semiflexible" connection.

HERCULES WIRE LACE: ()The material in this wire is too soft to withstand a great amount of wear. (2) It should not be used in belts having a driving tension of 35 pounds per inch of width or over, and running at high speeds. (3) The lacing for a four inch belt should be made with fewer holes than those tested so that the least cross-sectional area of the belt will be equal in strength to the strength of the lacing.

HOOK TYPE: (1) This type makes too rigid a connection, thereby causing an excessive amount of wear in the belt along the edge of the plate due to bending. (2) This type should not be used on small pulleys. (3) A connection is made more quickle with this type than with any other.

BLAKE BELT STUDS: (1) The Blake belt studs are well adapted for running on small pulleys and at comparatively high speeds.

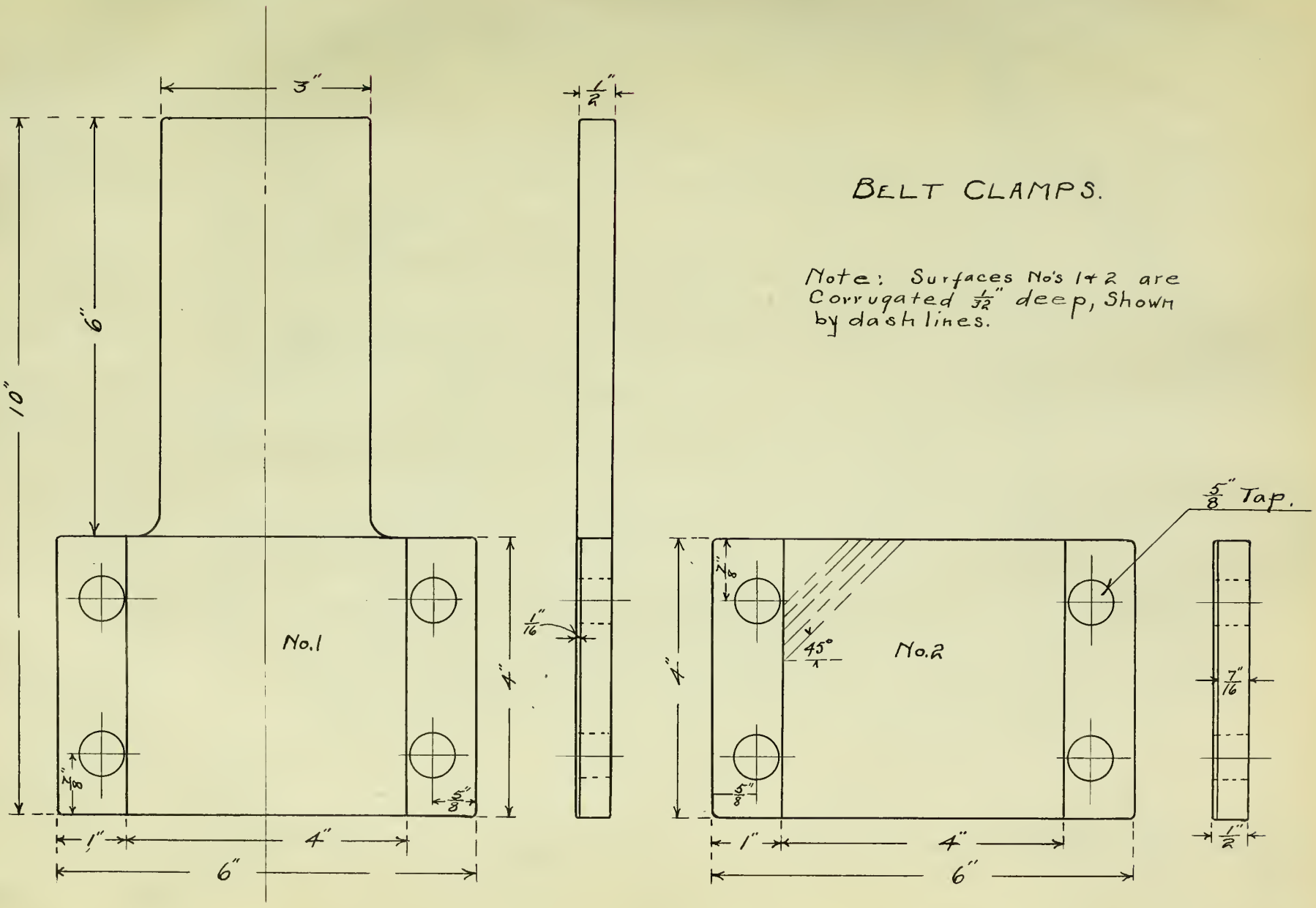

BELT CLAMPS.
Note: Surfaces No's 1 & 2 are Corrugated 1/32" deep, Shown by dash lines.
3"
1/2"
10"
9"
4"
1/16"
No.1
1"
4"
6"
5/8" Tap.
45°
No.2
7/16"

Fig. 1.

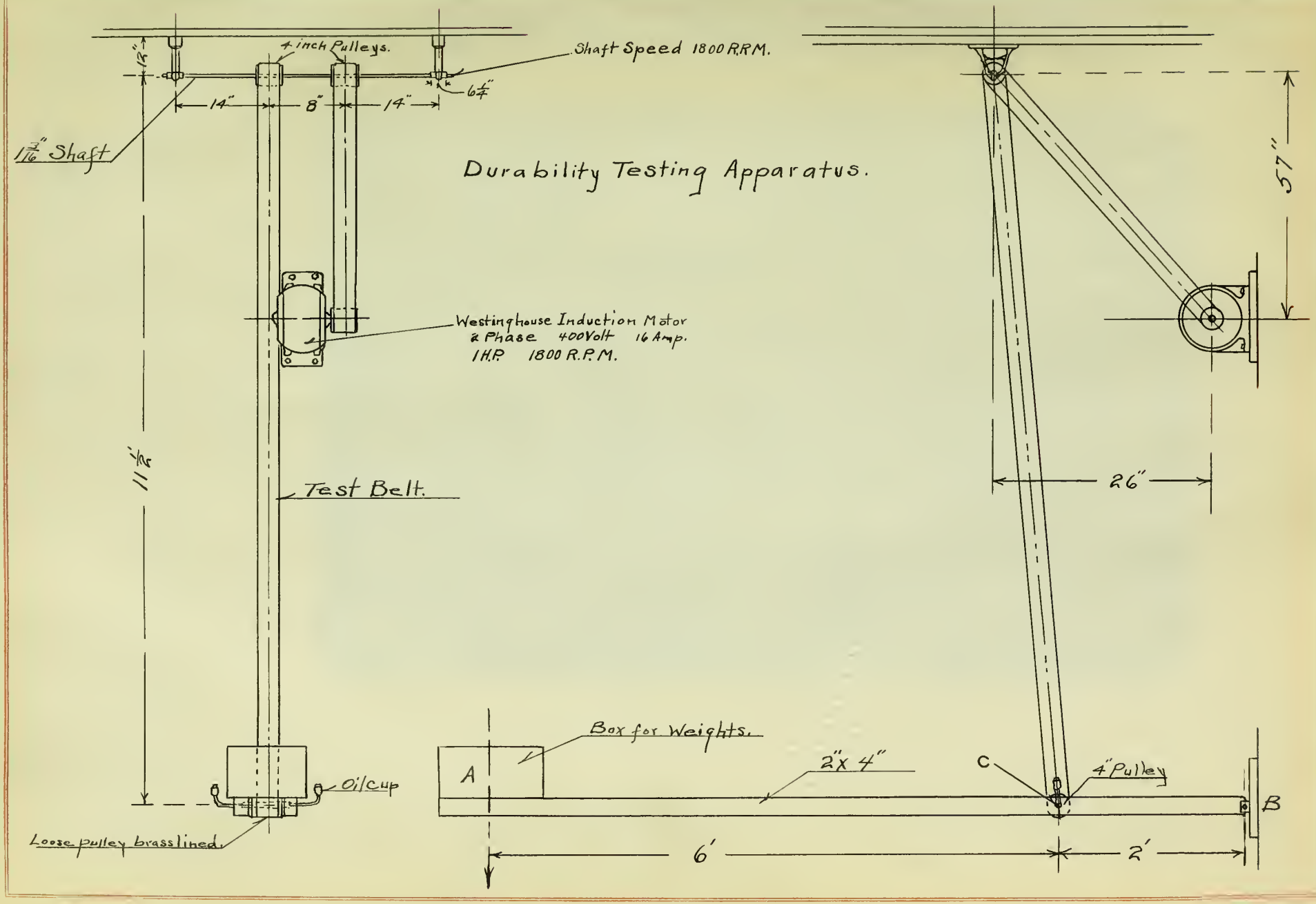
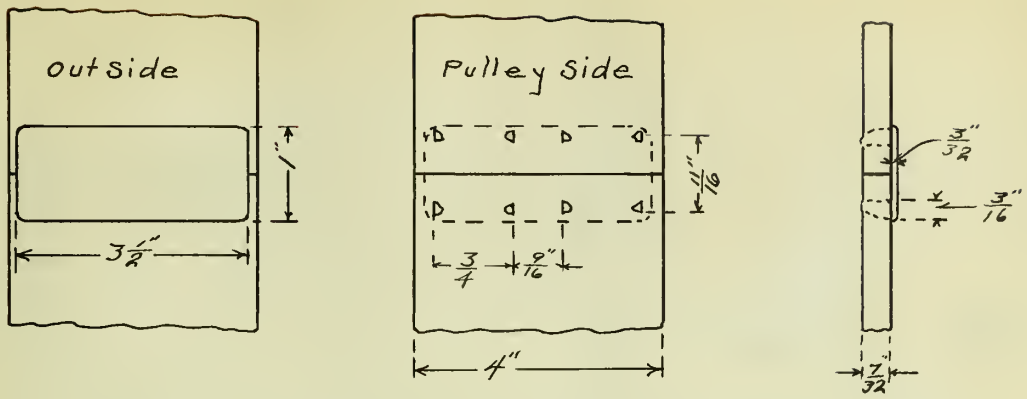

4 inch Pulleys.
Shaft Speed 1800 R.R.M.
1/4"
14"
8"
14"
6 1/4"
1 3/16" Shaft
Durability Testing Apparatus.
57"
Westinghouse Induction Motor
2 Phase 400 Volt 16 Amp.
1 H.P. 1800 R.P.M.
11 1/2"
Test Belt.
26"
Box for Weights.
A
2"x 4"
C
4" Pulley
B
Oil cup
Loose pulley brass lined.
6'
2'

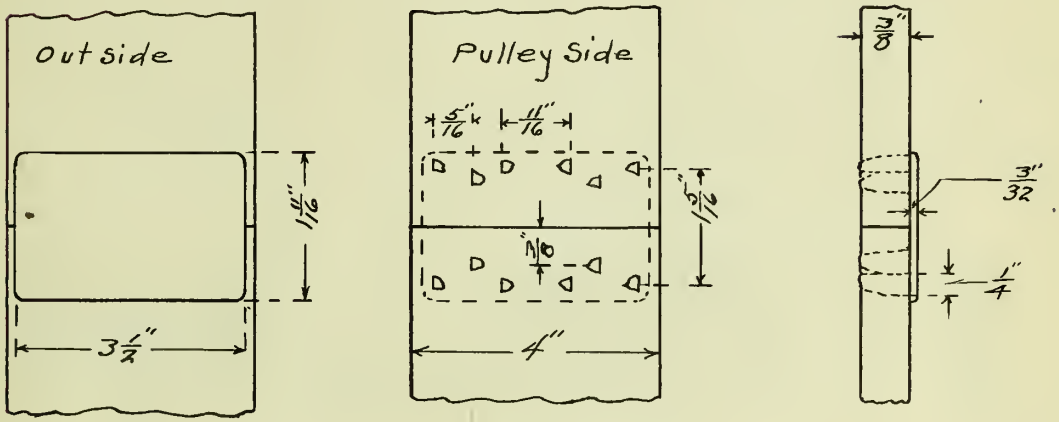
Fig. 2.

Olsen Tension Testing Machine.
Showing test Specimen in position.

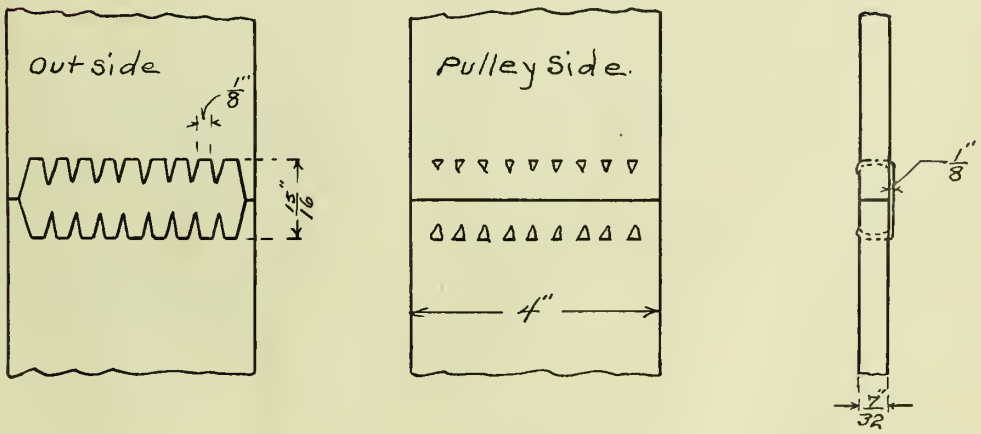
Fig. 3.



Jewell Belt Hook. (Malleable Iron)
Single Belt.

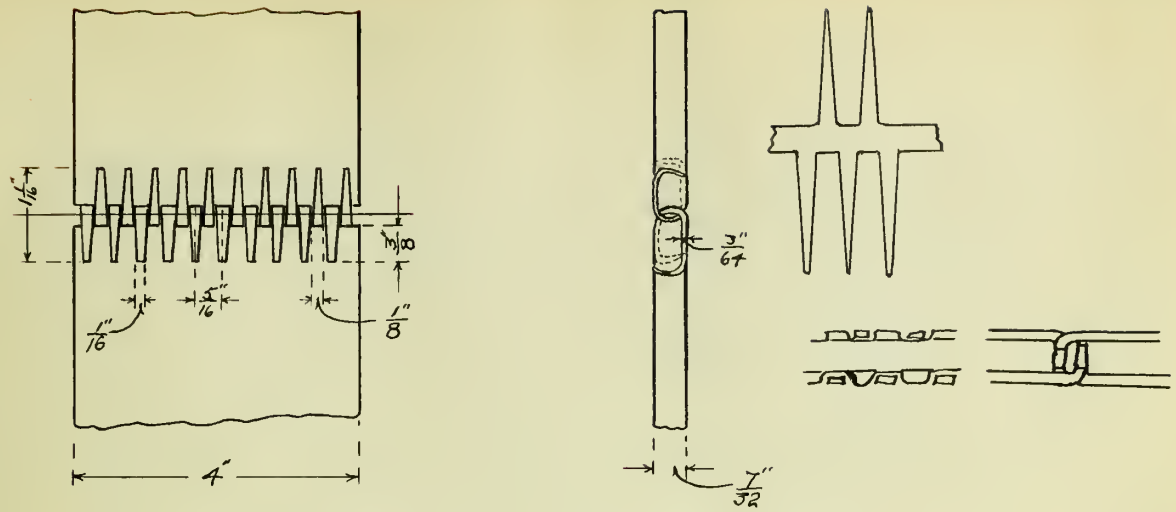


Jewell Belt Hook. (Malleable Iron)
Double Belt.

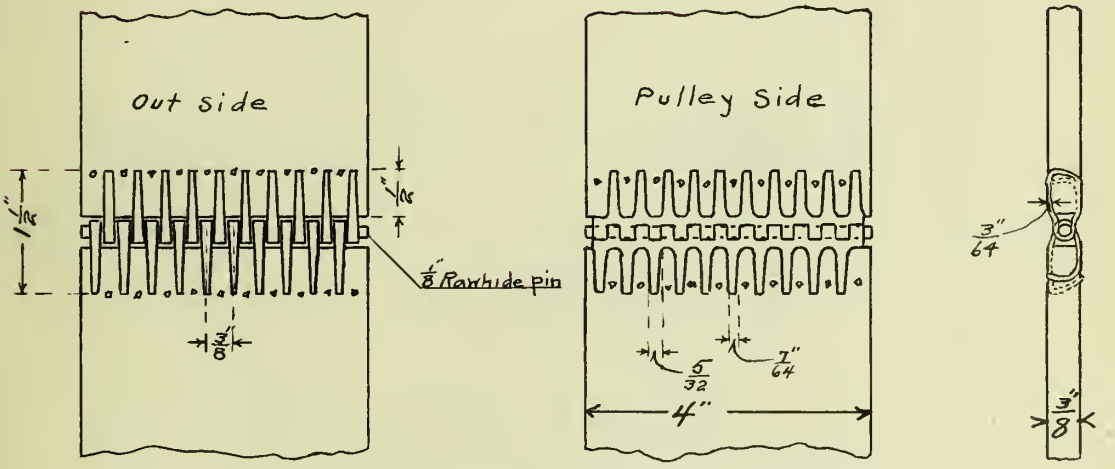


Bristol. (Steel). Single Belt.

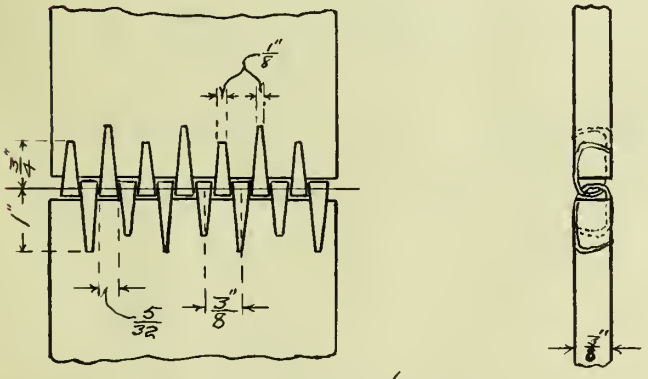
Fig. 4.



Semi-Flexible (Steel Hinge). Single Belt.



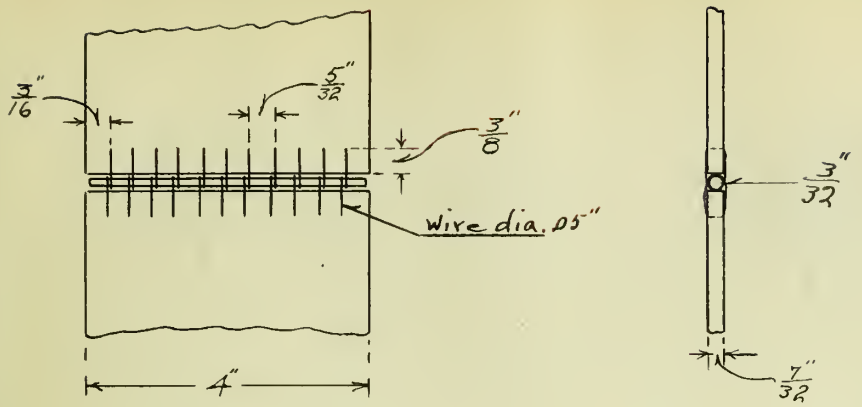
Flexible (Steel Hinge.) Single Belt.



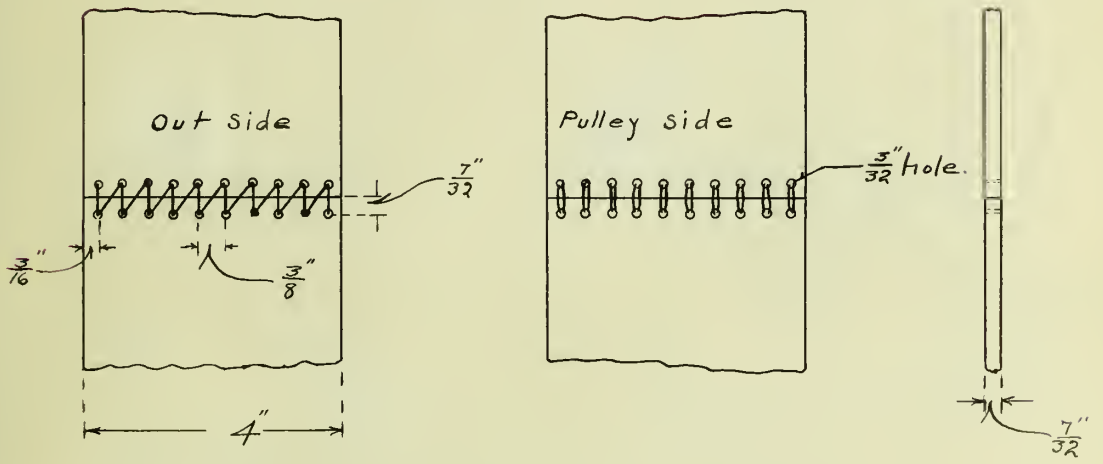
See detail above for single belt.

Semi-Flexible (Steel Hinge) Double Belt.

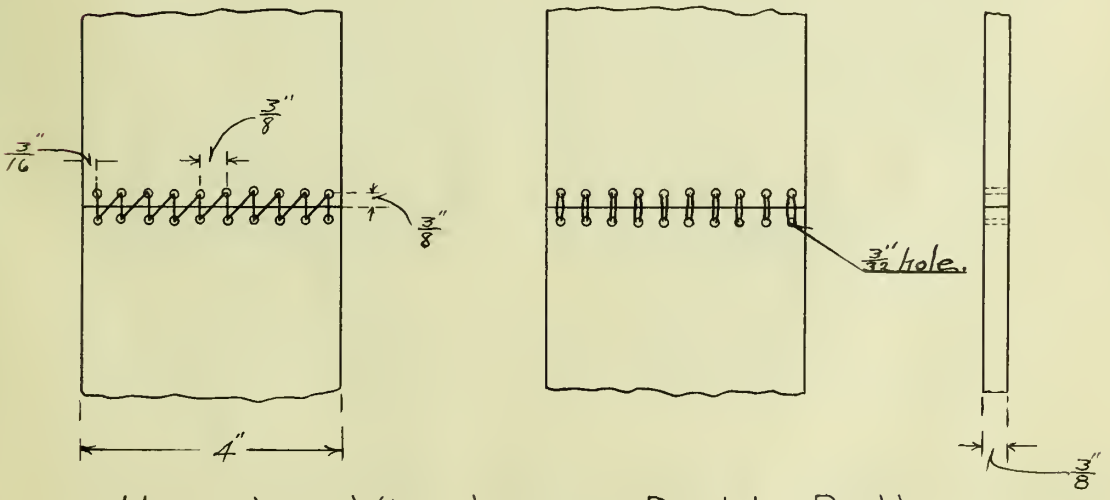
Fig. 5.



Jackson Machine Lace. Single Belt.

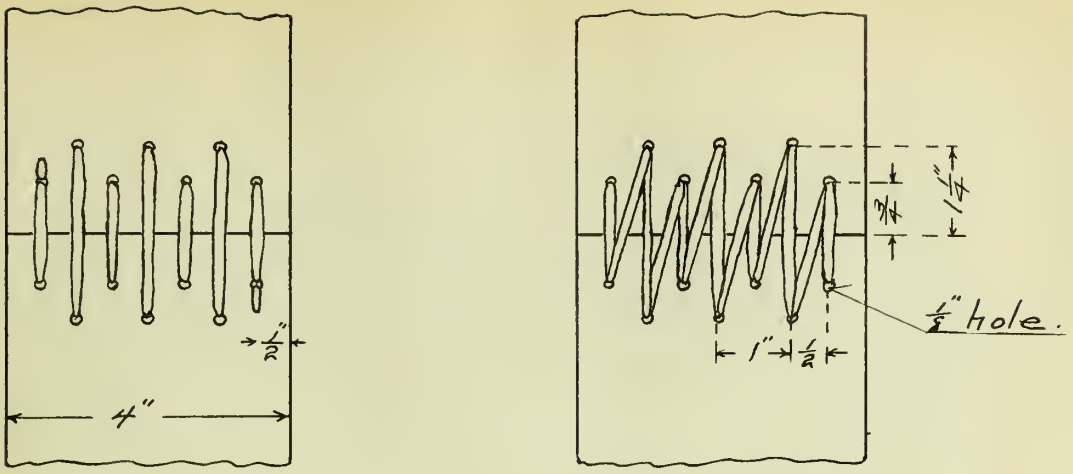


Hercules Wire Lace. Single Belt.

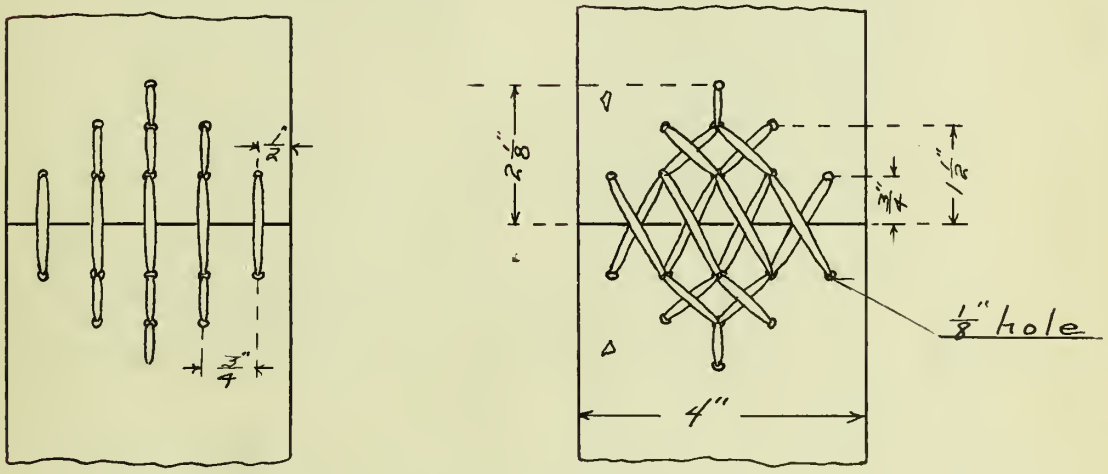


Hercules Wire Lace. Double Belt.

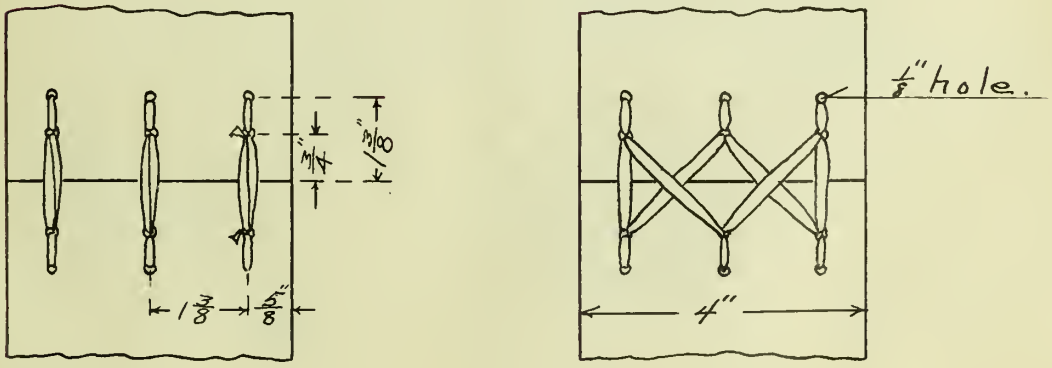
Fig. 6.



Rawhide Lace No. 2. Single and Double.

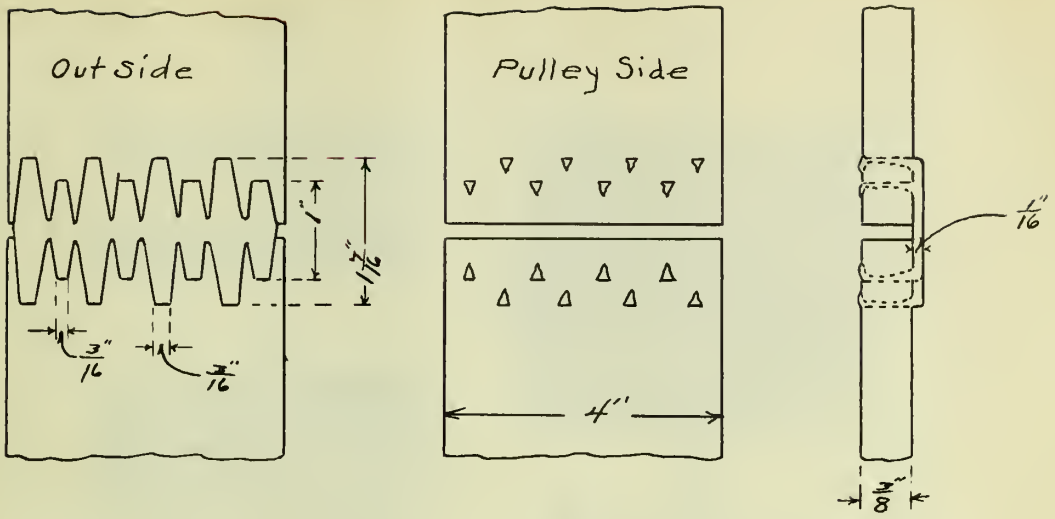


Rawhide Lace No. 4. Single and Double.

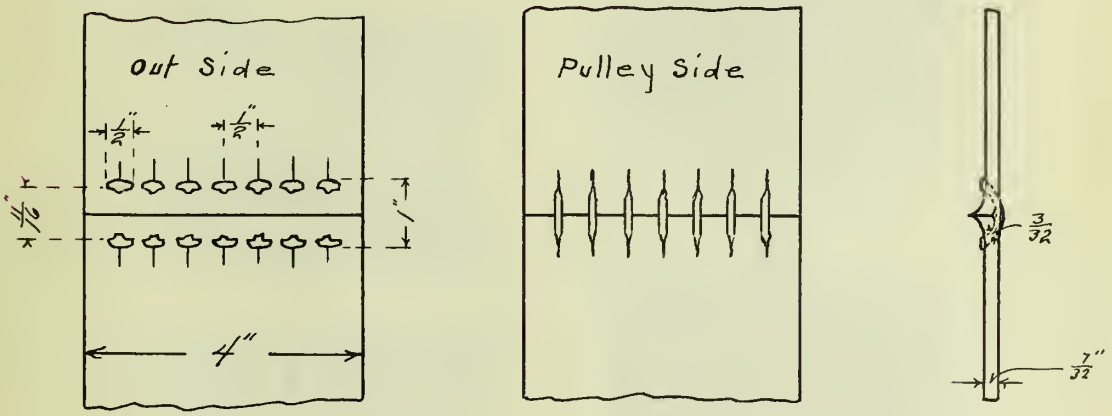


Rawhide Lace No. 3. Single and Double.

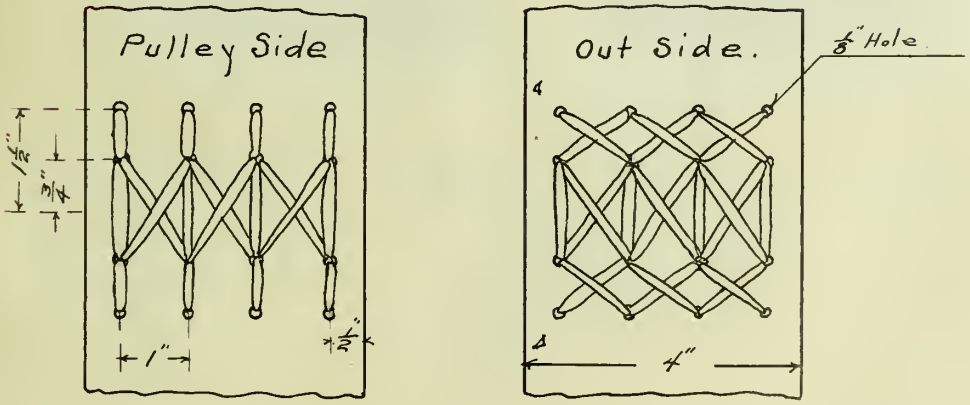
Fig. 7.



Bristol (Steel.) Double Belt.

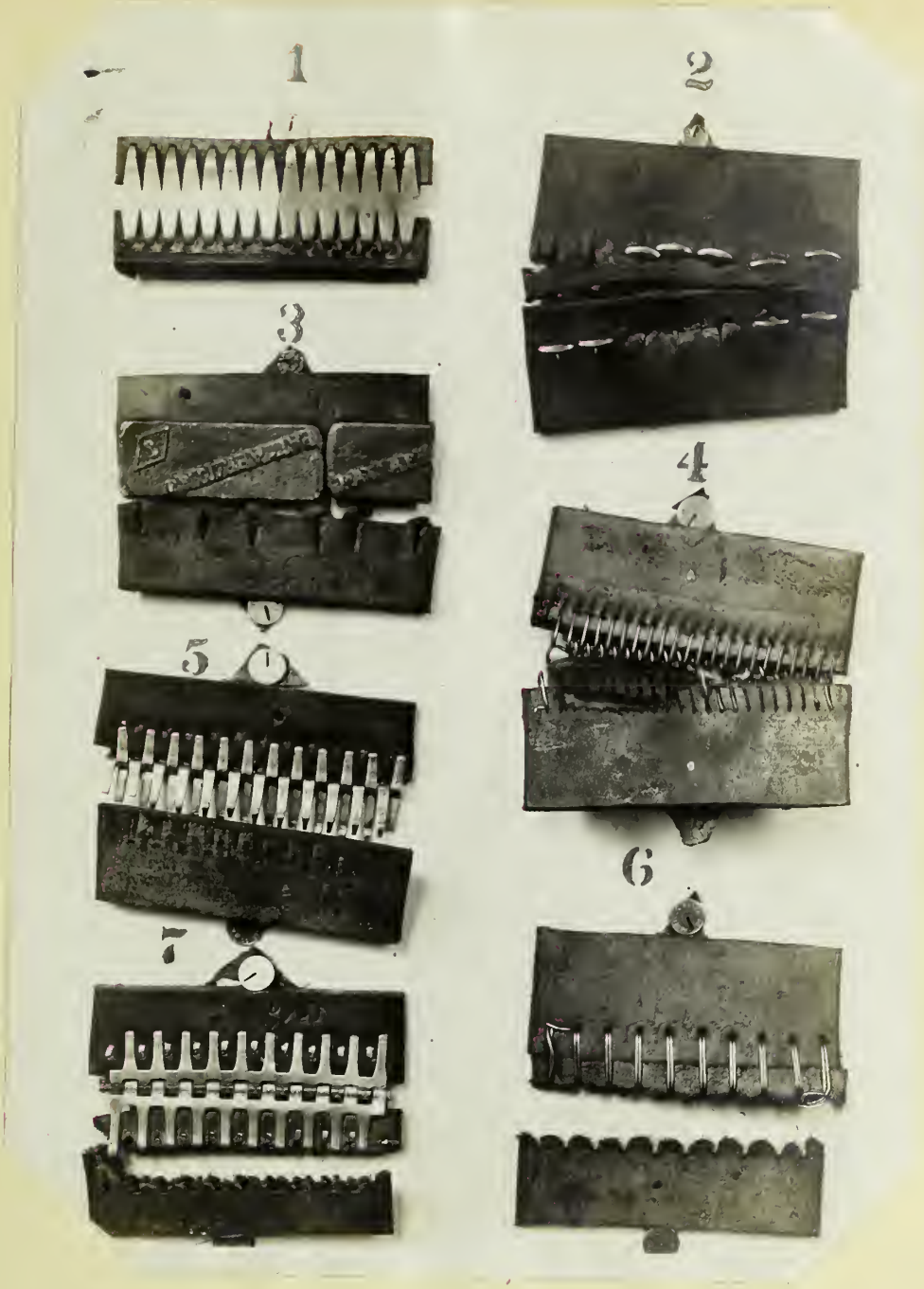


Blake. (Gun Metal) Single Belt.



Rawhide Lace No. 1. Single and Double Belt.

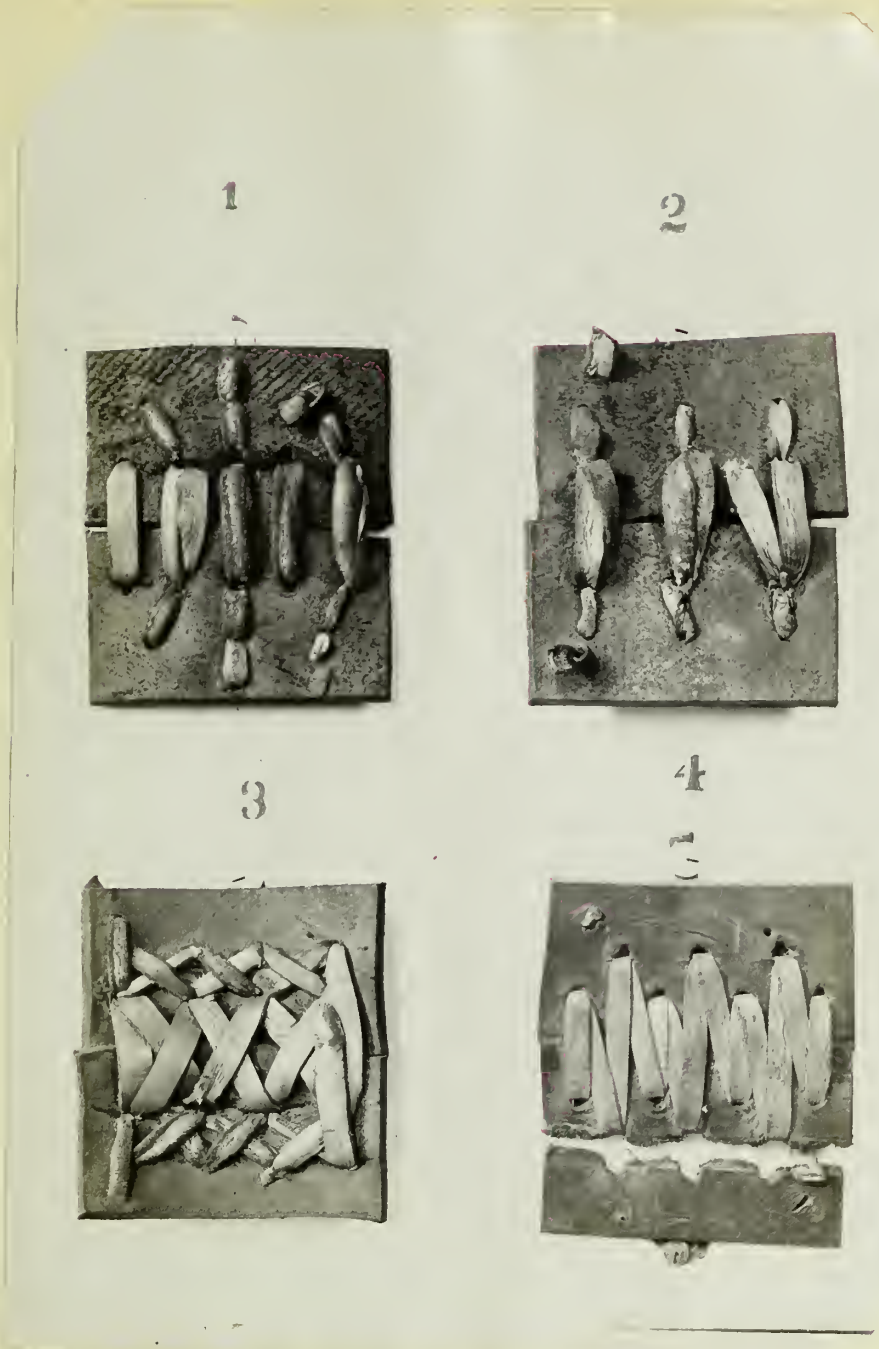
Fig. 8.



Tension Test Single Belt.

1. Bristol
2. Blake
3. Jewell
4. Jackson
5. Semi-Flexible
6. Hercules.
7. Flexible.

Fig. 9.



Tension Test Single Belt.

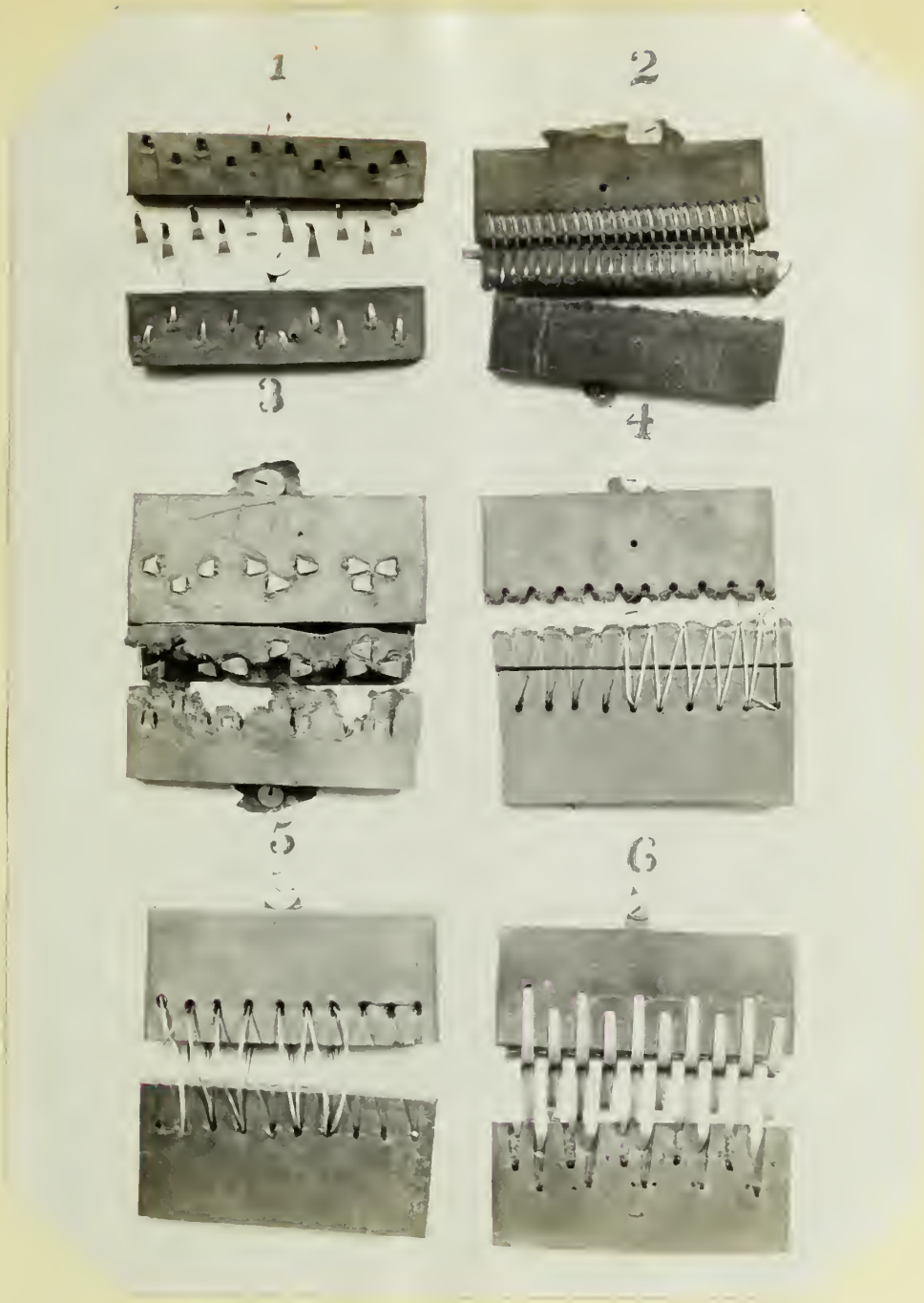
1. Rawhide No. 4
2. Rawhide No. 3
3. Rawhide No. 1
4. Rawhide No. 2.

Fig. 10

Durability Test Single Belt.

0. Bristol
1. Flexible
2. Jackson
3. Jewell
4. Semi-Flexible
5. Blake
6. Rawhide No. 1
7. Rawhide No. 3.
8. Rawhide No. 4.

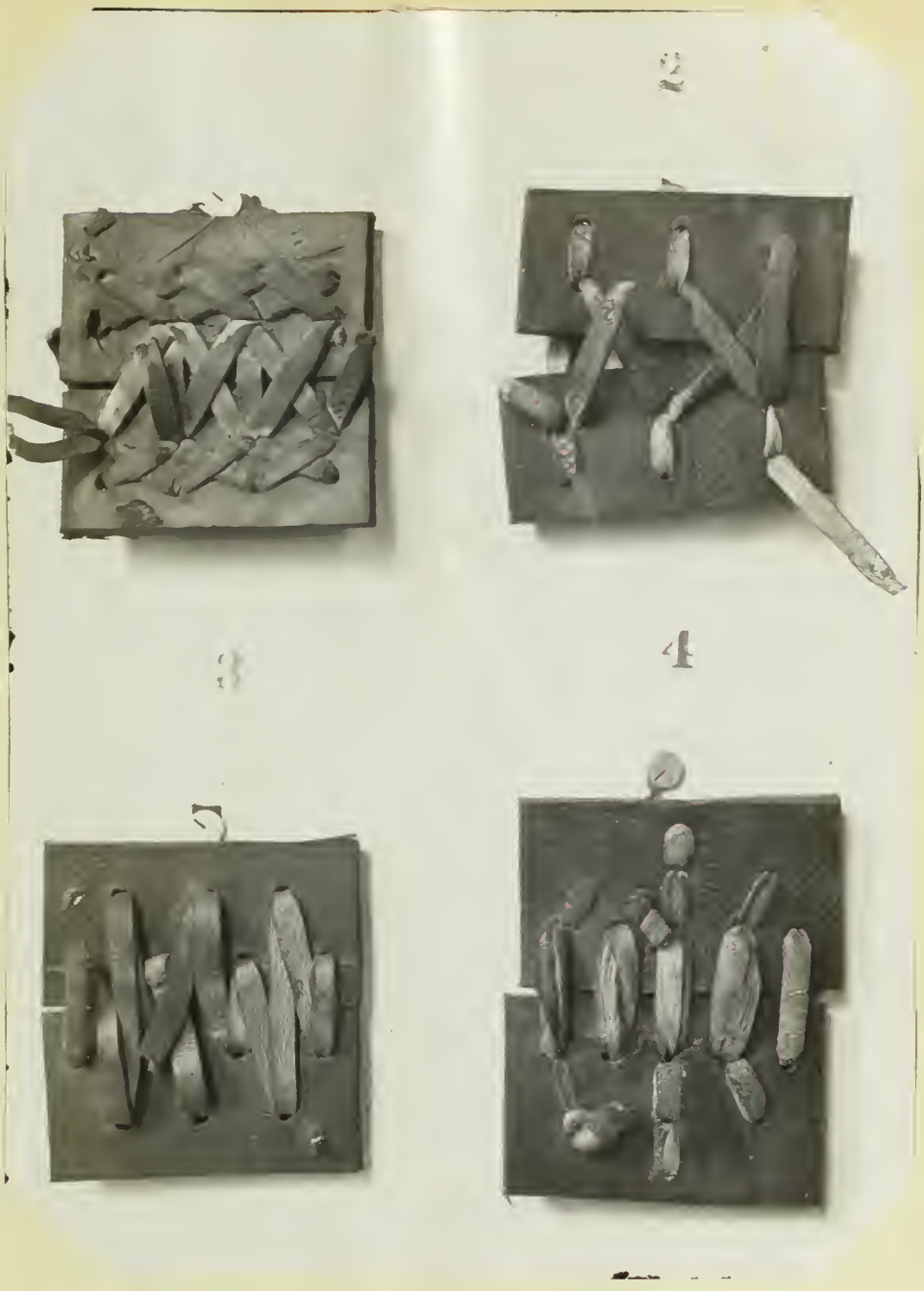
Fig. 11.



Tension Test Double Belt.

1. Bristol
2. Jackson
3. Jewell
4. Hercules
5. Hercules
6. Semi-Flexible.

Fig. 12.



Tension Test Double Belt

1. Rawhide No. 1 3. Rawhide No. 2

2. Rawhide No. 3 4. Rawhide No. 4.

Fig. 13.

Durability Test Double Belt.

1. Semi-Flexible
2. Jewell
3. Bristol
4. Jackson
5. Rawhide No. 4.
6. Rawhide No. 1

Fig. 14.

Side view of Durability Testing Apparatus.
Showing Belt in Position.

Fig. 15.

Tension Test Single Belt Connections. ($\frac{7}{32}$" x 4 inch)

Name of Lacing	Test No. Ultimate Tensile Strength lb. 1	2	3	Average Breaking Strength.	Av. per in. of Width lb.	Efficiency %	Av. Time to Make Connection.
	lb.	lb.	lb.	lb.			min.
Hercules	1715	1830	1670	1771	443	57.6	20
Jackson	1445	1500	1950	1631	408	53.0	
Rawhide No.2	1585	1465	1565	1538	384	50.0	20
Blake	1470	1520	1480	1490	372	48.4	20
Rawhide No.3	1350	1465	1550	1455	364	47.3	15
Flexible	1275	1500	1560	1445	361	47.0	5
Bristol	1225	1430	1450	1368	342	44.5	3
Semi-Flexible	1375	1300	1325	1333	333	43.4	5
Rawhide No.1	1200	1280	1350	1276	319	41.5	30
Jewell	1180	1250	1150	1193	298	38.7	5
Rawhide No.4	1110	1090	1260	1153	288	37.4	25

Table I

Durability Test Single Belt Connections. ($\frac{7}{32}$ X 4 inch)

Name of Lacing	Test No. Ultimate Tensile Strength lb. 1	2	Average Breaking Strength lb.	Av. per in. of Width lb.	No. Bends	Efficiency %	Deterioration %	Time to Make connection. min.
Blake	1390	1330	1360	340	116640	44.2	8.68	20
Bristol	1360	1260	1310	327	116640	42.5	4.50	3
Semi-Flexible	1260	1245	1252	313	116640	40.7	6.23	5
Flexible	1365	1130	1247	312	116640	40.5	13.82	5
Rawhide No.1	1050	1350	1200	300	116640	39.0	6.03	30
Jewell	1110	1075	1090	272	116640	35.4	8.52	5
Rawhide No.3	1035	1140	1087	272	116640	35.4	25.0	15
Rawhide No.4	955	1110	1032	258	116640	33.5	10.4	25
Rawhide No.2	$5\frac{3}{4}$ hrs.	ran 6hrs. 50m.	Av. 6hrs. 17min.		63074	0	100	20
Hercules	$2\frac{3}{4}$	2hrs. 35m	2hrs. 40m.		25920	0	100	15
Jackson Rawhide pin	1720	8hrs 10m.		430	79380	55.9	100	
Jackson Wire pin	6 hrs. 40m				64800		100	

Table II

Tension Test Double Belt Connections. ($\frac{3}{8}$ X 4 inch)

Name of Lacing	Test No. Ultimate Tensile Strength 1	2	3	Average Breaking Strength	Av. per in of Width	Efficiency	Av. Time to Make Connection.
	lb.	lb.	lb.	lb.	lb.	%	min.
Jewell	3250	3100	3200	3183	796	60.7	5
Jackson Rawhide pin.	3050	2790	2700	2846	711	54.2	
Hercules	2580	2770	2545	2631	658	50.2	15
Rawhide No.2	2320	2335	2245	2300	575	43.9	25
Bristol	2125	2250	2370	2248	562	42.8	5
Jackson Hemp pin.	2180	2280	2230	2230	557	42.5	
Rawhide No.1	2115	2215	2060	2130	532	40.6	40
Semi-Flexible	1900	1700	2275	1958	489	37.3	10
Rawhide No.4	2000	1490	1680	1723	431	32.9	30
Rawhide No.3	1190	1230	1320	1246	311	23.8	20

Table III

Durability Test Double Belt Connections. ($\frac{3}{8}$ X 4 inch)

Name of Lacing	Test No. Ultimate Tensile Strength 1 lb.	2 lb.	Average Breaking Strength lb.	Av. per in. of Width lb.	Number Bends	Efficency %	Deterioration. %	Av. Time to Make Connection. Min.
Jackson	2965	3450	3207	801	116640	61.8	None	
Jewell	1790	2760	2275	568	116640	43.4	28.5	5
Bristol	2130	2180	2155	538	116640	41.0	2.52	5
Rawhide No.4	1680	ran 11hrs. 50m.		420	116640	32.0	3.20	30
Rawhide No.1	1560	1650	1605	401	116640	30.6	24.6	40
Semi-Flexible	1240	1390	1315	328	116640	25.0	46.4	10
Rawhide No.3	ran 3hrs. 5min.	6hrs.	Av. 4hrs. 32m.		44064		100	20
Rawhide No.2	3½ hrs.	4hrs. 5m.	3hrs. 47m.		36774		100	25
Hercules.	35min.	41min.	38min.		6156		100	15

Table IV

Ultimate Tensile Strength of Belting

	Ultimate Strength lb. Test No. 1	2	3	Average lb.	Av. per in. of Width lb.
Double	3855	4060	3890	3936	1312
Durability Test	3780	4100	3740	3873	1291
Single	2310	2260	2365	2311	770
Durability Test.	2350	2285	2470	2368	789

Table V.

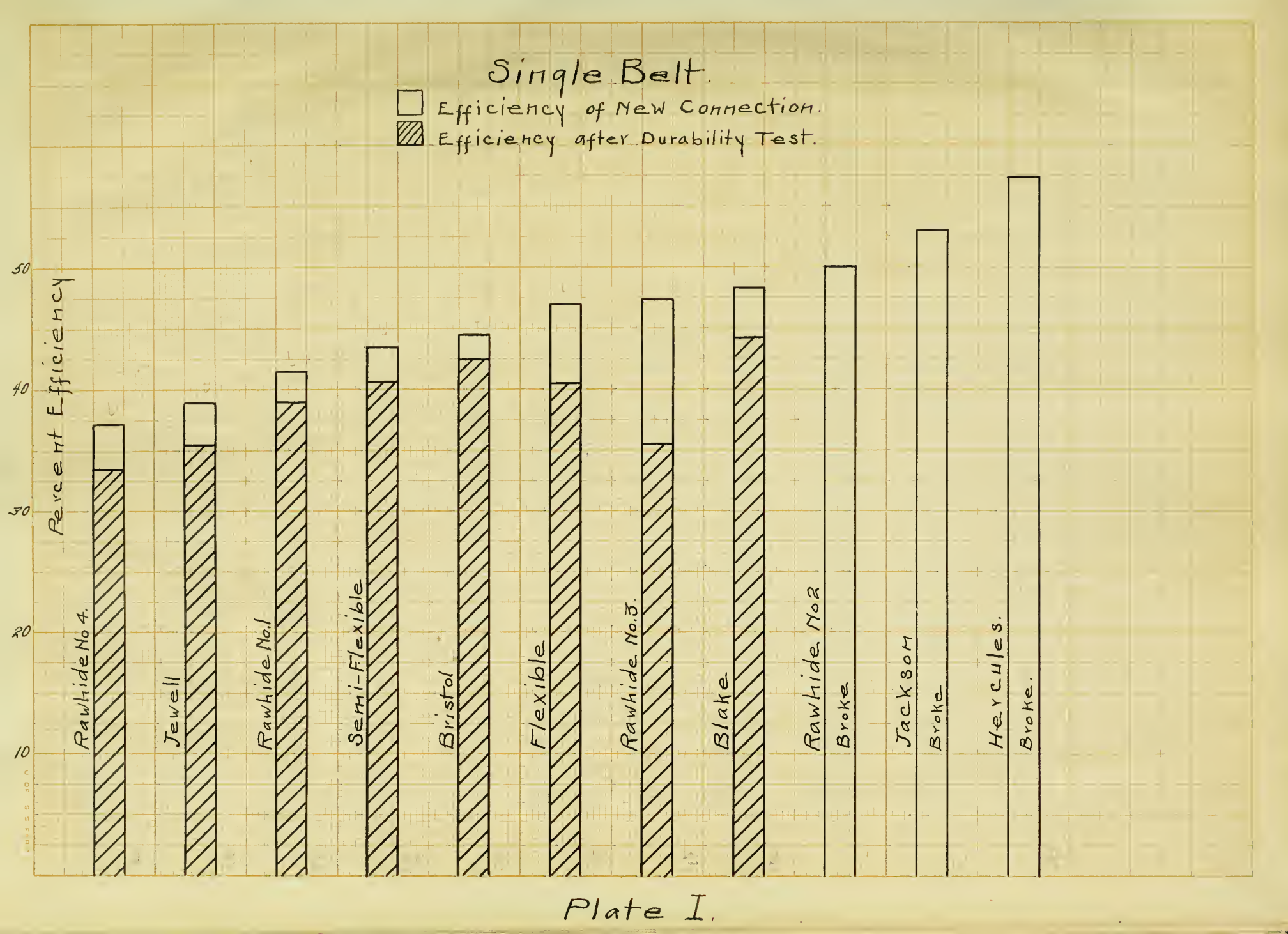

Single Belt.
Efficiency of New Connection.
Efficiency after Durability Test.
Percent Efficiency
50
40
30
20
10
Rawhide No 4.
Jewell
Rawhide No.1
Semi-Flexible
Bristol
Flexible
Rawhide No.3.
Blake
Rawhide No2
Broke
Jackson
Broke
Hercules.
Broke.

Plate I.

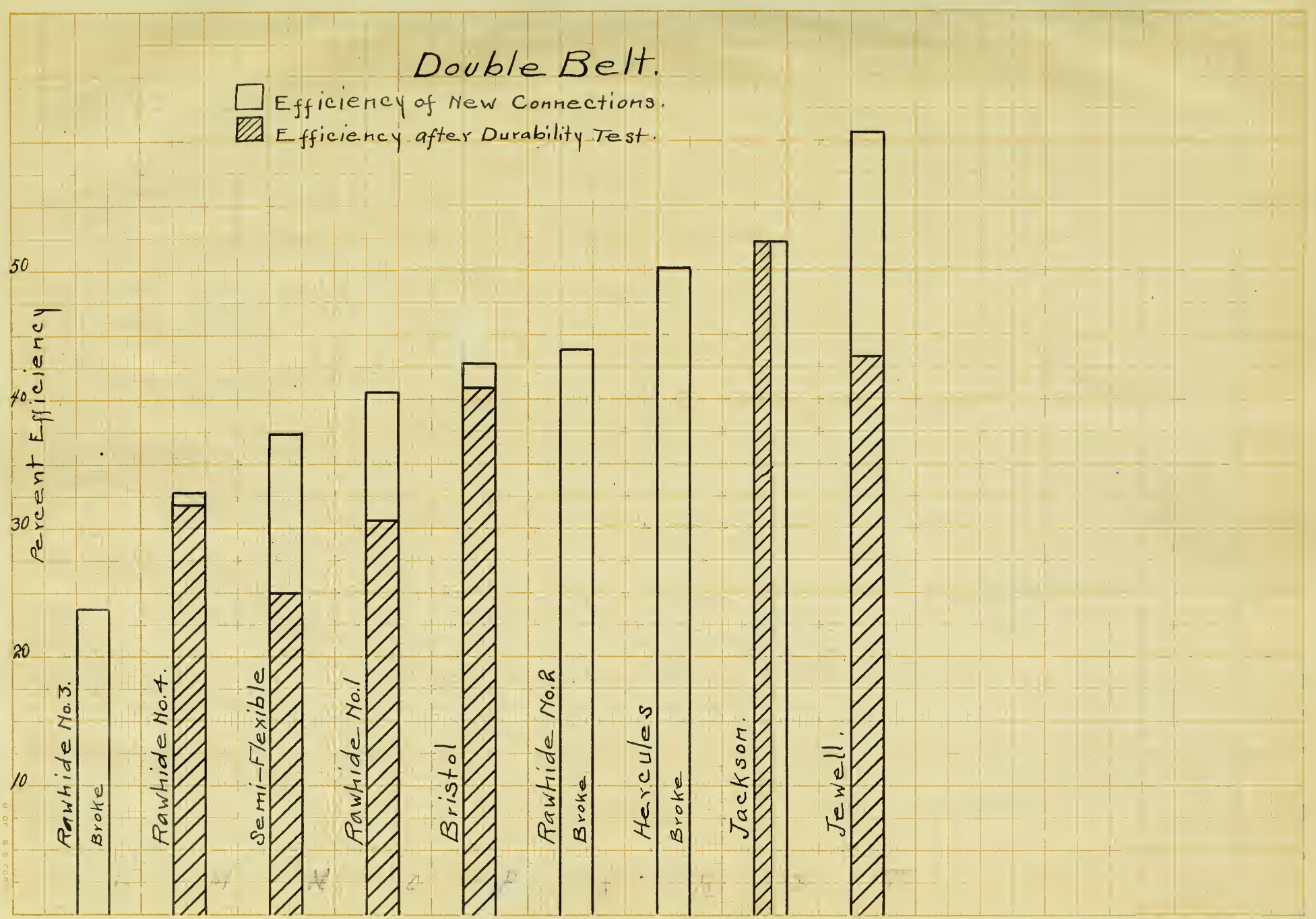

Double Belt.
Efficiency of New Connections.
Efficiency after Durability Test.
Percent Efficiency
50
40
30
20
10
Rawhide No.3.
Broke
Rawhide No.4.
Semi-Flexible
Rawhide No.1
Bristol
Rawhide No.2
Broke
Hercules
Broke
Jackson.
Jewell.

Plate II.

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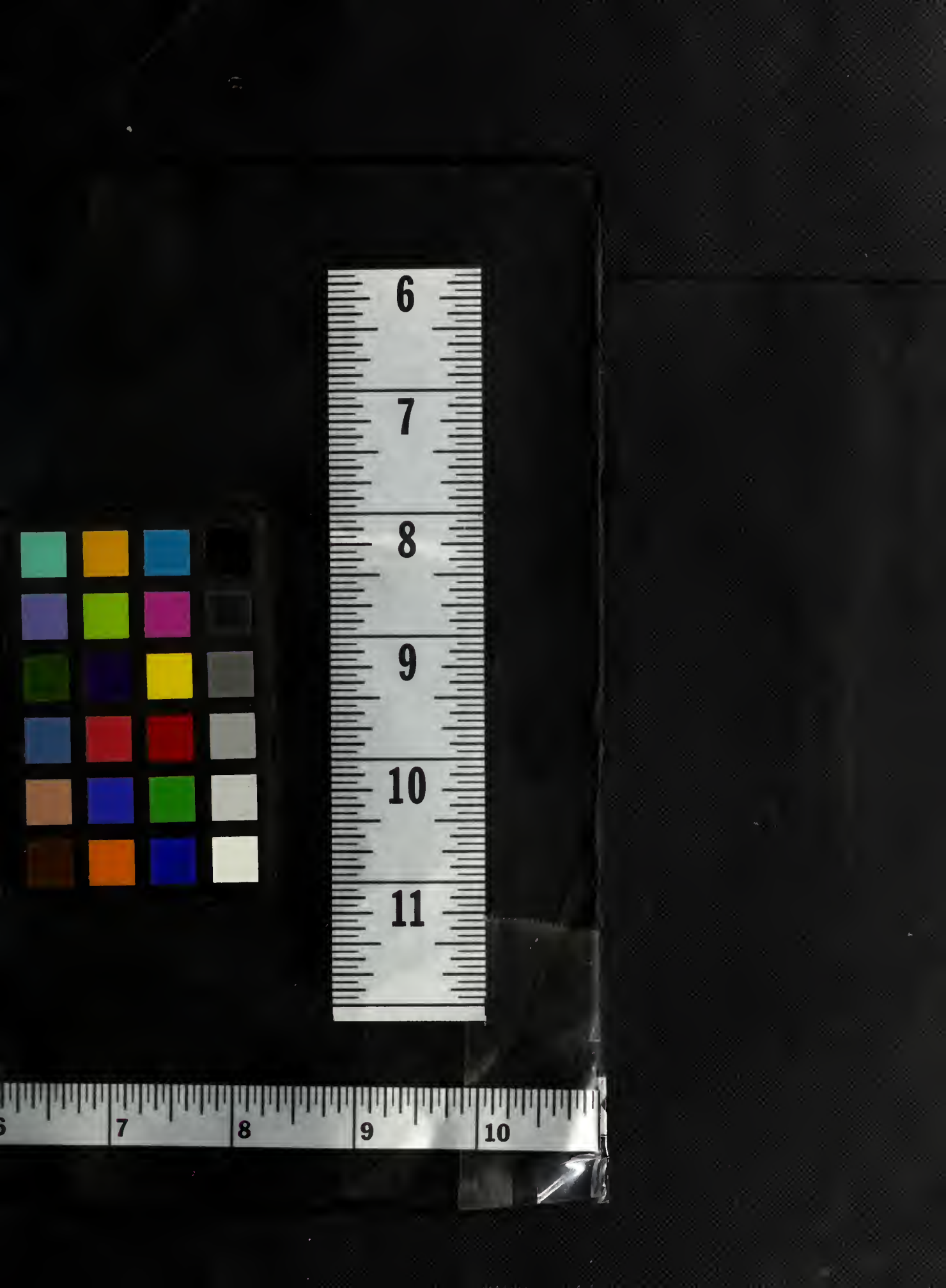
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